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THE EFFECT OF SEVERAL TYPES OF IRRIGATION WATER ON THE PH VALUE AND FREEZING POINT DEPRESSION OF VARIOUS TYPES OF SOILS

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A number of years ago it became one of the duties of this laboratory to examine numerous samples of water with the object of deciding whether or not they were suitable for irrigation purposes. Although various investigations on the toxicity of alkali salts have been carried out, it was soon realized that no experimental data were available which afforded any adequate basis for the interpretation of the results of analyses of alkali waters. Ordinarily sufficient consideration has not been given to the very important principle that the soil and water form a chemical system and that effects on plant growth must be correlated with modifications in the concentration and composition of the soil solution. Conclusions concerning the latter cannot be deduced from the composition of the irrigation water alone; in fact it is as necessary to consider the soil as the water. This opinion has recently been stated clearly by Kelly.[8]

When the experiments described in this paper were begun, it was the intention to make a rather extensive investigation of the effects of alkali waters on soils, but other projects have prevented the carrying out of this plan. It is thought worth while, however, to place on record the data which have been obtained, since these are based on several new methods of study not heretofore applied to similar problems except in a few instances. It is hoped that the present brief discussion may be of some value to other investigators who may plan more comprehensive researches on the effects of alkali waters in their relation to the chemistry of the soil and the nutrition of the plant.

The principal methods which have been employed by the writers include the determination of OH ion concentration by the hydrogen electrode and of total concentration in the soil solution by means of the freezing point depression, as described by Bouyoucos and McCool.[2] These methods have been thoroughly discussed elsewhere, and it will suffice now to state that the degree of alkalinity in the sense of OH ion concentration can only be studied at all accurately with the aid of the hydrogen electrode or by some equivalent method; ordinary titration procedures do not yield the necessary information. With regard to the total concentration, the freezing point depression affords the most direct method of determining this value for the soil solution (the free water of the soil with a total moisture content suitable for plant growth). For purposes of comparison, there are also included in the present investigation data obtained by analyzing soil extracts prepared by mixing one part of soil with five parts of water. In addition, conductivity measurements have been made on 1:1 extracts.

The waters used in the experiments were made in the laboratory by dissolving pure salts in distilled water. The composition of the artificially prepared waters was based on six different types, selected from data given in bulletins of the United States Geological Survey. After long standing in glass containers analyses of the waters were made, as they were used in the experiments. The analyses have been calculated in terms of characteristic groups as proposed by the United States Geological Survey.[10] This seems to be the most logical and convenient method for classifying waters with regard to those properties which are of interest to the geologist or agriculturist. Since this scheme of classification has not been employed in publications of agricultural experiment stations, it may be desirable to mention here that the reaction coefficient for any ion is the factor obtained by dividing the valence by the atomic weight. This factor multiplied by the concentration of the element in parts per million gives the reaction value. By this system of equivalents all ions are placed on the same basis and subsequent calculations are greatly simplified. The characteristic groups mentioned represent the percentage properties of the water and are independent of concentration. Thus different waters may be classified readily in this way irrespective of total concentration.

In table 1 are presented the analytical results on the six waters used, as well as their percentage content of the various groups of ions. In total salt content they range from a water of considerable purity

TABLE 1

COMPOSITION AND PROPERTIES OF WATERS

No.	Sodium* Na		Calcium Ca		Magnesium Mg		Carbonate CO_3		Bicarbonate HCO_3		Chlorine Cl		Sulfate SO_4		Silicate SiO_3		Total Solids	Percentage Characteristics			
	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Reaction value	P.P.M.	Primary Salinity Na-SO_4-Cl	Secondary Salinity Ca-Mg-SO_4-Cl	Primary Alkalinity Na-CO_3-HCO_3	Secondary Alkalinity Ca-Mg-CO_3-HCO_3
A	48.1	2.09	17.5	.87	65.4	5.38	9.6	.32	124.4	2.04	7.1	.20	273.3	5.68	3.8	.10	540	25.1%	45.4%	none	29.5%
B	525.3	22.85	3.0	.15	2.5	.21	331.2	11.02	34.2	.56	149.0	4.20	299.2	6.23	45.6	1.20	1390	45.0	none	53.5	1.5
C	473.8	20.61	7.0	.35	24.2	1.99	69.6	2.32	951.6	15.60	60.3	1.70	107.0	2.23	41.8	1.10	1260	17.1	none	72.7	10.2
D	27.4	1.19	5.0	.25	19.7	1.62	none	none	87.8	1.44	3.5	.10	70.0	1.45	2.5	.07	234	39.0	44.5	none	16.5
E	189.6	8.25	7.5	.38	5.0	.41	24.0	.80	417.2	6.84	35.5	1.00	15.6	.32	2.5	.07	504	14.7	none	76.6	8.7
F	378.0	16.44	45.5	2.27	7.9	.65	none	none	22.0	.36	613.4	17.30	80.2	1.67	1.3	.03	1256	85.0	13.0	none	2.0

*Calculated.

to several of rather high concentration. None of the waters, however, has a concentration of salts as high as that frequently found in naturally occurring waters.

It is necessary at this point to make a brief statement with regard to the terms ''alkali'' and alkalinity, since these may often be used in different senses. The term ''alkali'' is generally employed to designate a condition of high total salt content in a water or soil and subclasses are referred to as ''black'' and ''white'' alkali, without any very definite or consistent line of demarcation. In this paper the expression alkalinity is applied to that condition in the soil or water which is characterized by a higher concentration of OH ion than of H ion. This condition is the resultant of an equilibrium into which many factors may enter, such as carbonates, bicarbonates, dissolved CO_2, silicates, organic matter, etc. The two determinations then which are principally considered in this discussion are alkalinity as just defined and total concentration of salts. There is, however, no intention of giving the impression that other factors, such as the ratio of one element to another, may not be of great importance, but these questions cannot be answered with the data now at hand.

In the field the effect of an irrigation water on the soil solution will depend upon the total mass of soil reacting with the water, and upon the proportion of the products of the reaction not leached out. Thus the question of drainage is necessarily involved, and this is obviously a variable dependent on topographical conditions, soil texture, and the nature of the underlying strata. In the laboratory it is ordinarily practicable to study only the chemical effects of a given quantity of water on a definite mass of soil. In the present instance drainage effects are not considered, consequently the results may be interpreted as representing maximum effects in certain directions.

The first experiment was carried out with the use of three-gallon jars, in each of which were placed twenty pounds of air dry soil. Four different soils and a sample of beach sand were included, as shown in the tables. The first application consisted of two liters of water. After the soils had dried out, further applications were made, one liter at a time, until a total of seven liters had been added to each jar. The jars were kept outdoors, protected from rain, for a period of seven months. In the second experiment smaller quantities of soil were used. These were placed in large shallow covers of pottery, and water was added as in the first case, except that finally twice as much water was used in proportion to the soil. Two new soils, as well as pure silica sand, were included in this experiment. In both experiments the dried out soils were mixed and samples preserved in bottles.

It is of course impossible to compare exactly the quantities of water used with those employed in irrigation practice, since we should have to assume some maximum depth of penetration. In the first experiments the quantity of water added to the soil would be approximately equivalent to fourteen inches per acre, if all remained in the first foot of soil; in the second experiment about twenty-eight inches were used.

Hydrogen ion concentrations were determined with a hydrogen electrode apparatus, as described by Sharp and one of the authors.[13] Ten grams of dried soil were mixed with 30 c.c. of water. Within wide limits the proportion of soil to water did not appear to effect the H ion concentration very greatly. To a certain extent at least the soil mass, carbonates, silicates, etc., form a "buffer" system. It is of course impossible to state with certainty whether the OH ion concentration of the soil solution would be the same as that found in the extracts. According to Plummer,[11] in acid soils a greater concentration of H ion is found in the film water. It is conceivable that in alkaline soils a greater OH concentration might be found in the soil solution. It seems highly probable, however, that the general magnitudes measured are fairly representative of the soil solution. The effect of carbon dioxide must also be considered. As already pointed out elsewhere,[7] in certain alkaline soils, if a sufficient concentration of CO_2 is maintained in the atmosphere in contact with the soil, there may result a marked reduction in the OH ion concentration. It is unlikely, however, that most soils of high alkalinity would be capable of maintaining such a high CO_2 production, though the addition of large quantities of organic matter might tend to bring about such a condition. With regard to the freezing point depressions, these were made on the soils at optimum moisture content, and so should give an idea of the concentration actually existing in the soil solution.

The main results of the experiments are shown in tables 2 to 7. The first item for consideration is the OH ion concentration. These concentrations are expressed in the customary P_H values, as given in the tables prepared by Schmidt and one of the authors.[12] Neutrality is indicated by 7.0 and higher values denote increased concentrations of OH ion. Directing attention first to the three waters (B, C, E)

TABLE 2

EFFECTS OF ALKALI WATER "A" ON VARIOUS SOILS

Description of Soils	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts*							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1	8.7	8.9	......	.210	.396	....	....	....	....	1600	....	268	......	124	....	531	......
Clay adobe No. 2	7.0	......	7.1	.126	....	.213	2025	....	690	......	1575	......	122	....	50	......	584
Silty clay loam No. 3	7.2	7.3	7.1	.060	.064	.096	....	1805	1100	635	940	73	73	18	10	148	389
Fine sandy loam No. 4	7.0	7.6	7.8	.077	.050	.133	1655	2420	965	580	1165	98	61	18	10	99	336
Fine sandy loam No. 5	7.0	......	7.5	.031	....	.118	4970	....	925	630	1015	122	146	20	50	152	412
Beach sand No. 6	6.5	7.1	7.2	.035	.102	.180	4230	1920	540	545	1370	24	49	18	10	300	844
Silica sand No. 7	6.2	7.0	8.4	....	....	....	....	....	....	....	840	......	146	......	10	......	278

*The analyses of the water extracts of the untreated soils are omitted, since only negligible quantities of Cl and HCO_3 were present, except in the case of Soil 1.

TABLE 3

EFFECTS OF ALKALI WATER "B" ON VARIOUS SOILS

	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
Description of Soils	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1..............	8.7	8.9	......	.210	.321	....	....	....	....	1165	....	305	......	124	......	317	......
Clay adobe No. 2..............	7.0	......	7.5	.126	....	.468	2025	......	460	....	2000	......	134	......	280	......	611
Silty clay loam No. 3....	7.2	7.5	7.8	.060	.115	.202	....	985	595	915	1570	98	110	106	280	189	426
Fine sandy loam No. 4....	7.0	8.6	9.2	.077	.128	.350	1655	925	440	1045	1685	207	244	106	220	218	364
Fine sandy loam No. 5....	7.0	......	8.4	.031	....	.205	4970	......	640	885	1340	220	268	100	240	150	372
Beach sand No. 6..............	6.5	8.4	9.4	.035	.258	.428	4230	840	440	1105	1640	110	183	89	250	543	691
Silica sand.......... No. 7..............	6.2	9.5	9.8	0	....	....	....	....	....	....	1725	......	366 (CO_3) (192)	......	160	......	319

TABLE 4

EFFECTS OF ALKALI WATER "C" ON VARIOUS SOILS

Description of Soils	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1	8.7	9.1	......	.210	.465	....	....	....	....	1420	....	354	......	142	......	358	......
Clay adobe No. 2	7.0	......	8.1	.126	....	.342	2025	....	780	....	1480	......	171	......	140	......	329
Silty clay loam No. 3	7.2	7.8	8.7	.060	.089	.133	....	1600	990	655	1110	122	159	53	100	97	202
Fine sandy loam No. 4	7.0	9.3	9.5	.077	.108	.221	1655	1320	705	870	1500	268	317 (CO_3) (24)	53	100	119	193
Fine sandy loam No. 5	7.0	......	8.8	.031	....	.157	4970	....	1055	850	1060	256	354	50	80	107	189
Beach sand No. 6	6.5	8.4	9.9	.035	2.25	.369	4230	760	560	1250	1940	171	390 (CO_3) (12)	53	100	679	868
Silica sand No. 7	6.2	9.7	10.0	0	....	....	....	....	....	....	1395	......	317 (CO_3) (384)	......	60	......	76

TABLE 5

EFFECTS OF ALKALI WATER "D" ON VARIOUS SOILS

Description of Soils	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1............	8.7	8.9	......	.210	.267	....	....	....	....	1200	....	281	......	106	......	327	......
Clay adobe No. 2............	7.0	......	7.1	.126	....	.114	2025	....	1335	....	970	......	98	......	30	......	230
Silty clay loam No. 3....	7.2	7.2	7.1	.060	.077	.058	....	1885	2465	745	545	73	61	18	10	93	117
Fine sandy loam No. 4....	7.0	6.7	7.8	.077	.109	.090	1655	1060	1630	1070	785	61	73	18	20	150	113
Fine sandy loam No. 5....	7.0	......	7.7	.031	....	.054	4970	....	2025	475	540	134	146	10	10	164	117
Beach sand No. 6............	6.5	5.3	7.3	.035	.114	.127	4230	780	1800	750	1255	acid	37	18	10	348	755
Silica sand No. 7............	6.2	7.7	8.6	0	....	....	....	....	....	....	430	......	122	......	10	......	105

TABLE 6

EFFECTS OF ALKALI WATER "E" ON VARIOUS SOILS

Description of Soils	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1	8.7	9.0	......	.210	.282	....	....	....	....	955	....	331	......	71	....	212	......
Clay adobe No. 2	7.0	......	7.6	.126	....	.156	2025	....	1335	....	975	......	134	....	80	......	134
Silty clay loam No. 3	7.2	7.2	8.0	.060	.073	.067	....	1845	2155	485	575	73	98	53	50	56	65
Fine sandy loam No. 4	7.0	8.1	8.9	.077	.072	.155	1655	1715	1145	670	960	171	171	35	60	138	92
Fine sandy loam No. 5	7.0	......	8.3	.031	....	.101	4970	....	1670	510	1150	171	232	40	60	31	51
Beach sand No. 6	6.5	7.8	8.5	.035	.189	.246	4230	680	960	1925	1600	61	159	53	30	1146	216
Silica sand No. 7	6.2	9.1	9.7	0	....	....	....	....	....	....	680	......	305 (CO_3) (96)	....	30	....	39

TABLE 7

EFFECTS OF ALKALI WATER "F" ON VARIOUS SOILS

Description of Soils	PH Soil Suspension			Freezing point depression at optimum moisture content			Specific Resistance (25°C.) 1:1 Water Extract			Analyses of 1:5 Water Extracts							
										P.P.M. Air Dry Soil							
										Total Solids		Bicarbonate HCO_3		Chloride Cl		Sulfate SO_4	
	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	Un-treated soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per-9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil	7 liters water per 9 kilos soil	14 liters water per 9 kilos soil
	PH	PH	PH	°C.	°C.	°C.	ohms	ohms	ohms	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Clay adobe No. 1	8.7	8.6	......	.210	.516	....	....	....	....	1575	....	281	......	426	....	257	......
Clay adobe No. 2	7.0	......	6.7	.126	....	.861	2025	....	275	....	3205	......	85	......	1130	......	202
Silty clay loam No. 3	7.2	7.0	6.7	.060	.120	.433	....	1145	330	765	2670	73	49	195	1050	64	113
Fine sandy loam No. 4	7.0	7.4	7.2	.077	.220	.633	1655	705	310	1155	2840	98	61	195	980	741	154
Fine sandy loam No. 5	7.0	......	7.3	.031	....	.433	4970	....	310	1290	2265	98	122	460	910	78	144
Beach sand No. 6	6.5	4.5	6.5	.035	.299	.643	4230	760	480	1650	1950	acid	37	195	730	852	385
Silica sand No. 7	6.2	6.8	6.7	0	....	....	....	....	....	....	1735	......	39	......	530	......	78

with the characteristic of high primary alkalinity, it is evident that the effect on the OH ion concentration of the soil varies significantly, depending on the soil. Soil 1, a clay adobe, is already very alkaline and no appreciable changes occur in the OH ion concentration. Soil 2, another clay adobe, of practically neutral reaction, is increased only slightly in OH ion concentration, even by the larger proportions of water. In soil 3, a silty clay loam, the effect on the alkalinity is more marked, but becomes excessive only in the case of water C, which has a high percentage of primary alkalinity as well as a high concentration value. The fine sandy loams, soils 4 and 5, are influenced very decidedly in their alkalinity even by a water of such low concentration as E. Some of the OH ion concentrations found in these sandy soils are very high from the standpoint of plant nutrition. In the beach sand and pure silica sand the maximum effects are observed. Clearly we may draw the general conclusion from the above data that, other conditions being equal, a far greater effect is produced on the alkalinity of a sandy type of soil than on that of a heavy soil.

It may reasonably be assumed that the explanation of these observations rests on the different chemical and physical composition of the various soils. Possibly in the soils containing large clay fractions chemical reactions take place between some of the silicates and the added alkaline salts, resulting either in precipitation or the formation of new silicate compounds. Surface adsorption also doubtless plays some part in the reduction of alkalinity noted. In the sandy soils these chemical and physical reactions are much less marked and the originity alkalinity of the irrigation water is therefore more effective in increasing the alkalinity of the soil solution. In the pure sand the alkalinity is simply the resultant of the chemical reactions taking place between the constituents of the water as evaporation proceeds, the final OH ion concentration being dependent on the state of equilibrium existing between CO_3, HCO_3, CO_2, etc.

We may next inquire how the measurements obtained by the use of the hydrogen electrode compare with results derived from titrating water extracts for CO_3 and HCO_3, with phenolphthalein and methyl orange as indicators. In only two cases are normal carbonates found in the soil extracts, even when the OH ion concentration of the soil is high. In the soils with the highest concentration of this ion are also found high values for the HCO_3 titration, but there is no exact relationship. A very significant difference may be found in OH ion concentration without a corresponding difference in titrations. An agreement could scarcely be expected, inasmuch as the OH ion concentration is the resultant of numerous factors which influence the dissociation and hydrolysis of the carbonates and silicates present, while the titration represents a total content of soluble alkaline salts capable of producing OH ion as the equilibrium changes during the titration. These considerations would suggest that the determination of the OH ion concentration of the soil has greater value than the customary titration. By using the colorimetric method suggested by Gillespie[3] in place of the hydrogen electrode the OH ion determination could be made more conveniently, perhaps, than the titration. It should also be considered that during the filtration through the Pasteur filter under added pressure of air (and CO_2) the relation of CO_3 and HCO_3 may be changed.

The total concentration of the soil solution as evidenced by freezing point determinations is particularly affected by the waters having a high percentage of primary salinity. In this case also the nature of the soil is of great importance. The greatest effect is produced in the soils of lighter texture. The exact concentration, of course, is dependent upon the moisture content of the soil, for, as Bouyoucos[1] has shown, in heavy soils only a small proportion of the total water is present in the free state. With similar decreases in moisture content, therefore, a much greater increase in concentration of solution may take place in a heavy soil than in a sandy one. The total solids in the extracts reflect fairly well the relative concentrations in the soil solution, although the freezing point depressions may frequently give a better picture of the probable injurious effects on plants, since it is the concentration of the soil solution and not that of the extract which is important. The total concentration of the extract may be estimated very conveniently by the conductivity method.

In table 8 are presented data for a number of California soils commonly recognized as ''alkali'' soils. Comparisons may be made between these and the normal soils treated with the alkali waters. It will be noted that in a number of cases the comparatively limited amounts of water used in the experiment have brought about OH ion concentrations comparable with those found in the so-called ''black alkali'' soils. The total concentration of salts is extremely high in a number of these soils and several times the quantity of the most concentrated water would have been necessary to reproduce this condition in the soils under investigation. These higher concentrations, however, are extremely detrimental or even fatal to plant growth.

TABLE 8

CHARACTERISTICS OF VARIOUS ALKALI SOILS

No.	PH	Freezing point depression*	Specific Resistance (25°C.) 1:1 Water Extract	Analyses of 1:5 Water Extracts P.P.M. Air Dry Soil					Remarks
				Total Solids	Carbonate CO_3	Bi-carbonate HCO_3	Chlorine Cl	Sulfate SO_4	
		°C.	ohms	p.p.m.	p.p.m.	p p.m.	p.p.m.	p.p.m.	
1	9.4	.869	90	9650	120	415	1684	2251	"white alkali", surface 6 inches, 20% germination.
2	8.7	1.044	205	4150	none	134	1117	1239	"white alkali," surface 6 inches, stunted seedlings.
3	8.3	.786	140	10790	none	134	3511	2708	Marshy spot, stunted seedlings.
5	8.0	4.600	45	30260	none	98	6418	12296	No germination.
8	9.2	2.400	55	17850	132	317	3617	6313	"white alkali," stunted seedlings.
9	10.4	1.590	115	7000	1692	659	479	1144	"black alkali," no germination.
10	9.9	.872	205	3935	348	256	745	897	20% germination.

*Freezing point determinations made at optimum moisture content.

It is now desirable to discuss the foregoing data from a general point of view and with reference to certain previous publications. Much of the earlier work in this field was due to Hilgard,[5] and many of the facts and ideas presented by him are still in use as a basis for judging the value of waters for irrigation purposes. It seems very necessary to modify these first teachings, however, in the light of more recent experiments. It is highly essential that the soil be considered as a chemical system in which the effect of any water will be modified by the chemical and physical reactions in the soil. The views of Kelley[8] in this connection have already been referred to, and some experiments by Lipman and Gericke[9] also suggest the necessity of considering the effect of the soil. These investigators found, by examining water extracts of a soil to which various alkali salts had been added, that less of Na_2CO_3 was recovered than of NaCl or Na_2SO_4. Evidently it is not sufficient to calculate simply the quantity of sodium salts added to an acre of soil by a given number of inches of irrigation water. Such a method of calculation does not take into account the chemical and physical reactions in the soil nor the precipitations occurring when the water evaporates.

The general statement is often made that an alkali water may be used without danger if the soil is of a well drained sandy type, but may become injurious when applied to a heavy soil. In view of data such as those presented in this paper it should be recognized that the possibility of injury may be much greater in a sandy soil than in a heavy soil unless the sandy soil is completely drained. If this drainage is prevented by any underlying impervious strata it would seem possible that a condition distinctly injurious to many plants might be quickly produced in a sandy soil. This seems to be particularly true of waters tending to increase the OH ion concentration of the soil solution. That a relatively slight increase in OH ion concentration may be unfavorable to seedlings has been shown in a previous investigation.[6]

The above conclusions have received confirmation in a recent article by Harris and Pittman.[4] In an extensive investigation in which freezing point determinations were made as well as analyses of water extracts it was shown that the soil exerts a most pronounced effect on the salts added, particularly in the case of Na_2CO_3. In connection with calculations based on freezing point depressions made by the authors just cited, it may be useful to point out that it is not possible to compute the extent to which a given quantity of salt will increase the depression of the freezing point in a soil of optimum moisture content, unless account is taken of the free and unfree water as proposed by Bouyoucos.[1] Thus if the total moisture content is used in the calculations it might appear that the depression was greater than could be accounted for by the added salt, since the water effective for solution is less than the total water present.

The data on which a correlation of injury to the plant and the composition and concentration of the soil solution could be based are very inadequate. Certain previous experiments[6] have shown that the environment for seedlings may become unfavorable with comparatively slight increases in OH ion concentration. High total concentrations of any salts are unfavorable, but the exact relations between the ions which may bring about malnutrition of the plant remain to be worked out. In order to gain a preliminary idea of the effect of the total and of the OH ion concentrations brought about in the various soils after treatment with the waters described in this paper, portions of the treated soils were placed in tumblers and germination tests were made with barley and pea seeds. The inhibiting effect of high OH ion concentrations was especially noted in this experiment. In certain cases still other factors might enter into the question; for example, there is a possibility that with higher concentrations of OH ion the solubility of Fe or PO_4 might be decreased, perhaps bringing about such low concentrations of these elements in the soil solution that the plant would be unable to obtain sufficient quantities for its nutrition. In brief, the whole field is so complicated that it appears advisable to investigate one by one such factors as admit of definite measurement. It is hoped that this paper may suggest certain possibilities in this direction.

SUMMARY

1. A number of different waters of interest from the standpoint of irrigation have been applied to soils of several types. The effects on the freezing point depressions and on the OH ion concentrations of the soils have been determined.

2. Waters with a high percentage of primary alkalinity applied even in moderate quantities produced greatly increased OH ion concentrations. The effect was far greater in sandy soils than in heavy soils.

3. Waters with a high concentration of alkali salts soon produced excessive concentrations in the soil solution as shown by the freezing point depressions. This was especially true of sandy soils.

4. The determination of the OH ion concentration and freezing point depression of soils frequently may be more convenient in practice and more useful as a basis of interpretation than the ordinary procedures used in analyzing alkali soils.

5. Any appreciable increases in OH ion concentration of the soil (especially when exceeding PH 8.5) appear to be injurious to seedlings.

6. It is suggested that the geological method of classifying waters and the use of reaction values provide methods of expression which are very useful in interpreting the results of analyses of waters intended for irrigation purposes.

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